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Ductile - Ductile Beryllium Aluminum Metal Matrix Composite Manufactured by Extrusion[1]

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1.0 Introduction

Beryllium-aluminum alloys are unique, in-situ ductile-ductile metal matrix composite alloys. Cast and extruded beryllium-aluminum composite alloys are expected to have a unique combination of properties that are attractive for applications such as ground and space based interceptor and tracking systems that require minimum weight, high stiffness, good damping capacity and thermal stability. Compared with other metal matrix composites, cast and extruded beryllium-aluminum composites are expected to have the advantages of: (1) lower cost; (2) significantly higher ductility; (3) higher temperature capability; (4) less directionality of properties; (5) applicability of all conventional metal processing techniques; and (6) joining by conventional welding and brazing technology.

The current program is designed to develop a method for extruding a cast beryllium-aluminum composite, establish a basis for estimating the properties that can ultimately be achieved with an optimized process, and produce an extruded structural shape of moderate complexity. Specific technical objectives are as follows:

1. Develop an extrusion process suitable for beryllium-aluminum composites that maximizes product yield, minimizes processing steps, gives good surface finish, and is suited for producing complex shapes.

2. Determine mechanical and physical properties to demonstrate potential.

3. Define potential for property enhancements and cost reductions that could be achieved through continued development of this technology.

2.0 Work Plan

The work covered by this program is divided into two main tasks and a number of subtasks. Task 1 involves the development of extrusion parameters. For this task, three ingots will be cast, each measuring approximately 47.5 mm diameter by approximately 200 mm length. The diameter of the ingots has been increased slightly from the original plan to ensure that a high quality surface finish can be achieved on the ingots prior to extrusion billet preparation. The ingots will be cast with a nominal composition of 65Be-33Al-2Ag (by weight percent). Each ingot will be cut in half to provide six cylindrical billets for extrusion.

Different pre-extrusion billet canning/coating techniques will be evaluated to determine the optimal conditions that produce extrusions having the best surface quality. The can or coating helps prevent surface cracking and aids lubrication.

Three billet preparation techniques will be evaluated. The first will be to enclose the billet in a metal sleeve or can. Sleeves of 6061 aluminum will be evaluated at thicknesses of 0.635 mm and 1.905 mm; a copper sleeve with a thickness of 1.905 mm will also be evaluated. The second billet preparation technique will be to plasma spray an aluminum alloy coating onto two billets, with coating thicknesses of 0.635 mm and 1.905 mm. The final billet surface will be plated with copper with a plated coating thickness of 0.635 mm.

The six billets will be extruded through a round die as a group using similar extrusion parameters. Extrusion parameters will be selected based on results from previous NMI IRAD work. The extruded rods will be evaluated primarily for the effects of billet preparation on surface finish. Overall product integrity will also be evaluated.

Task 2 will lead to development of the capability to extrude a structural shape of moderate complexity of beryllium-aluminum composite. Three beryllium-aluminum ingots will be cast in molds measuring 63.5 mm diameter by approximately 200 mm length. The method of extrusion billet preparation will be selected based on the results of Task 1. The extrusion shape selected for this program is a modified I beam, and is representative of types of shapes previously used with other metal matrix composite materials. Extrusion conditions will be optimized based on results of the first two extrusions in Task 2 and the optimized conditions will be applied to the third extrusion. Extruded product will be evaluated for surface quality, mechanical properties and microstructure.

3.0 Work Accomplished

Task 1:

Four of the six billets planned for Task 1 of this program have been extruded and evaluated. These billets were prepared from cast beryllium-aluminum ingots with nominal composition of 65Be-33Al-2Ag (by weight percent) as follows:

1. Billet 590A was prepared by enclosing the cast beryllium-aluminum ingot in a 6061 aluminum sleeve having a thickness of 1.905 mm. The billet was evacuated, then sealed by welding.

2. Billet 590B was prepared as above, but with a 6061 aluminum sleeve having a thickness of 0.635 mm.

3. Billet 589A was prepared as above, but with a copper sleeve having a thickness of 1.905 mm.

4. Billet 589B was prepared by plating copper onto the beryllium-aluminum ingot to a thickness of 0.635 mm. The plating technique used yielded a high quality copper coating for the extrusion billet.

The two billets with aluminum cans (590A and 590B) were heated to 425°C, then extruded with a ram speed of 5 inches per minute on the 340 ton capacity press at NMI. The two billets with copper cans (589A and 589B) were heated to 450°C, then extruded with a ram speed of 25 inches per minute. The die size for all extrusions was 0.425 inches, corresponding to a reduction ratio (the ratio of the starting cross-sectional area to the final cross-sectional area) of 15.25:1. This reduction ratio was selected to be similar to the reduction ratio required for the Task 2 shaped extrusions.

The four billets were successfully extruded. Examination of the surfaces of the extruded rods revealed small differences in surface quality. The best surface quality was seen for the rod extruded from billet 589B, which had been plated with a thin layer of copper. The surface of this rod was smooth and uniform over the entire length of the rod. The rod extruded from billet 589A, which had been canned in a thicker copper sleeve, also had a uniform surface that was only slightly rougher than the surface on 589B.

The surface of the rod extruded from billet 590A, which had been canned in a thicker aluminum sleeve, was rough over the entire length of the rod. The appearance of this rod suggested that the billet had either been overheated, or that insufficient lubrication had been used. The surface of the rod extruded from billet 590B, which had been canned in a thin aluminum sleeve, was smooth except for a few blisters. Although the overall surface quality of the billets extruded with copper cladding was better than the extrusions made with aluminum cladding, the results suggest that further development should lead to the capability of producing high quality beryllium-aluminum extrusions with aluminum

cladding as well.

Microstructural evaluation of transverse and longitudinal sections from each extruded rod was done with the scanning electron microscope (SEM). Samples were evaluated for cladding uniformity, cladding/beryllium-aluminum interfacial features, and general microstructural features of the extruded composite. Micrographs of longitudinal and transverse sections of each extruded rod are shown in Figures 1 and 2.

The extruded beryllium-aluminum microstructures show uniform deformation of the beryllium phase (dark imaging phase) and of the aluminum phase (light imaging phase). Uniform cladding thickness is observed on all longitudinal sections (figure 1 b and d, figure 2 b and d). Cladding thickness on extrusions 589A and 590A measures 580μ; cladding thickness on 589B and 590B measures 250μ and 270μ respectively. Transverse sections (Figure 1 a and c, figure 2 a and c) show greater roughness at the cladding/beryllium-aluminum interface, particularly for the aluminum clad extrusions. Improvements to interfacial roughness may be achieved by providing a better surface finish on the beryllium-aluminum ingots prior to canning.

Higher magnification examination of the aluminum cladding/beryllium-aluminum interfaces for extrusions 590A and B revealed continuity between the aluminum cladding and the aluminum phase of the beryllium-aluminum composite. Examination of the copper cladding/beryllium-aluminum interfaces for extrusions 589A and B showed the presence of a thin copper-aluminum intermetallic layer (<4μ) at the interface.

Task 2:

The shaped extrusion die required for this task has been received at NMI. Two beryllium-aluminum ingots measuring 2.5 inches in diameter have been cast for the shaped extrusions. Plans have been developed to recast these ingots for improved casting integrity.

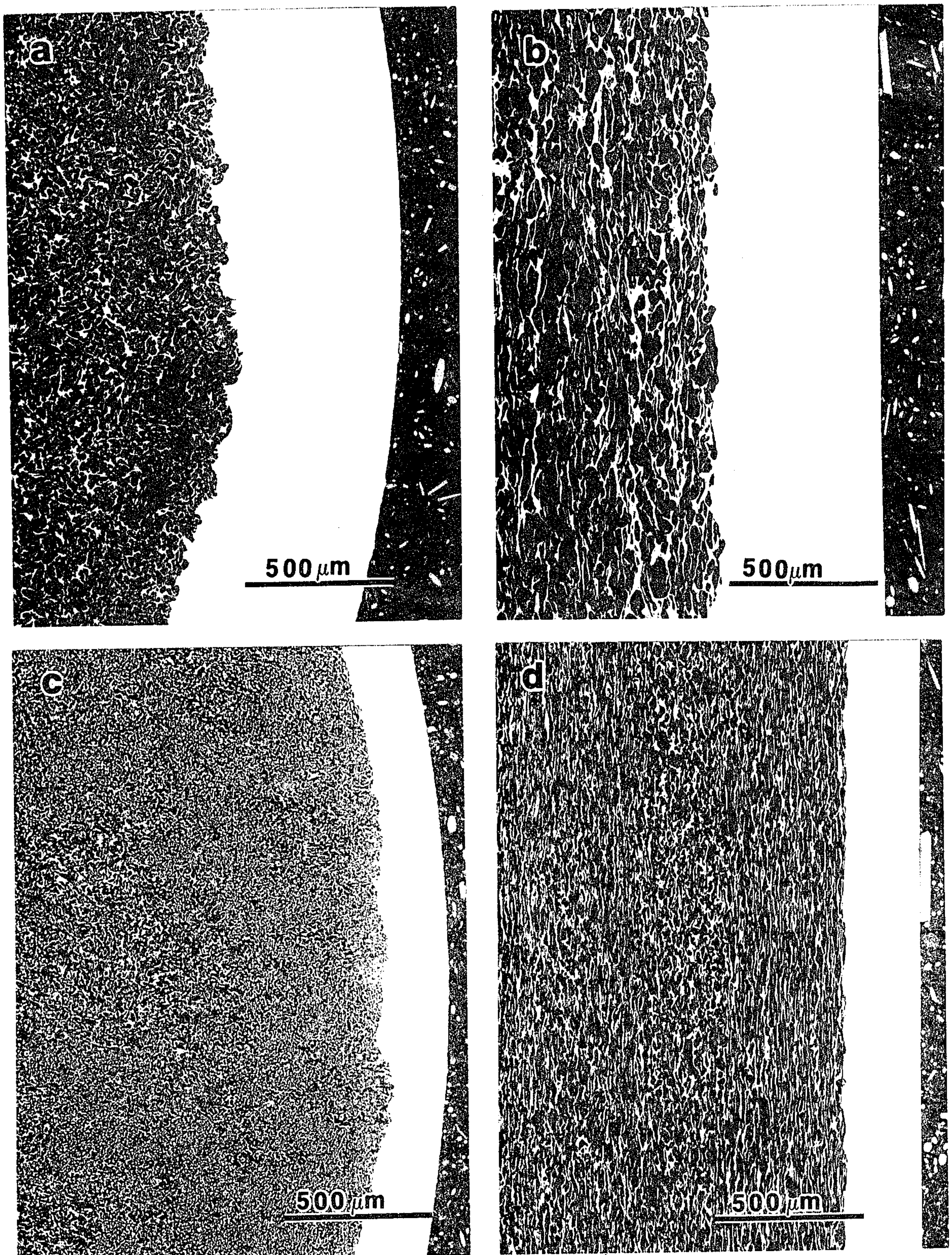

Figure 1. Backscatter electron images showing Cu clad surfaces of extruded Be-Al. (a) 589A, transverse section, (b) 589A, longitudinal section, (c) 589B, transverse section, (d) 589B, longitudinal section.

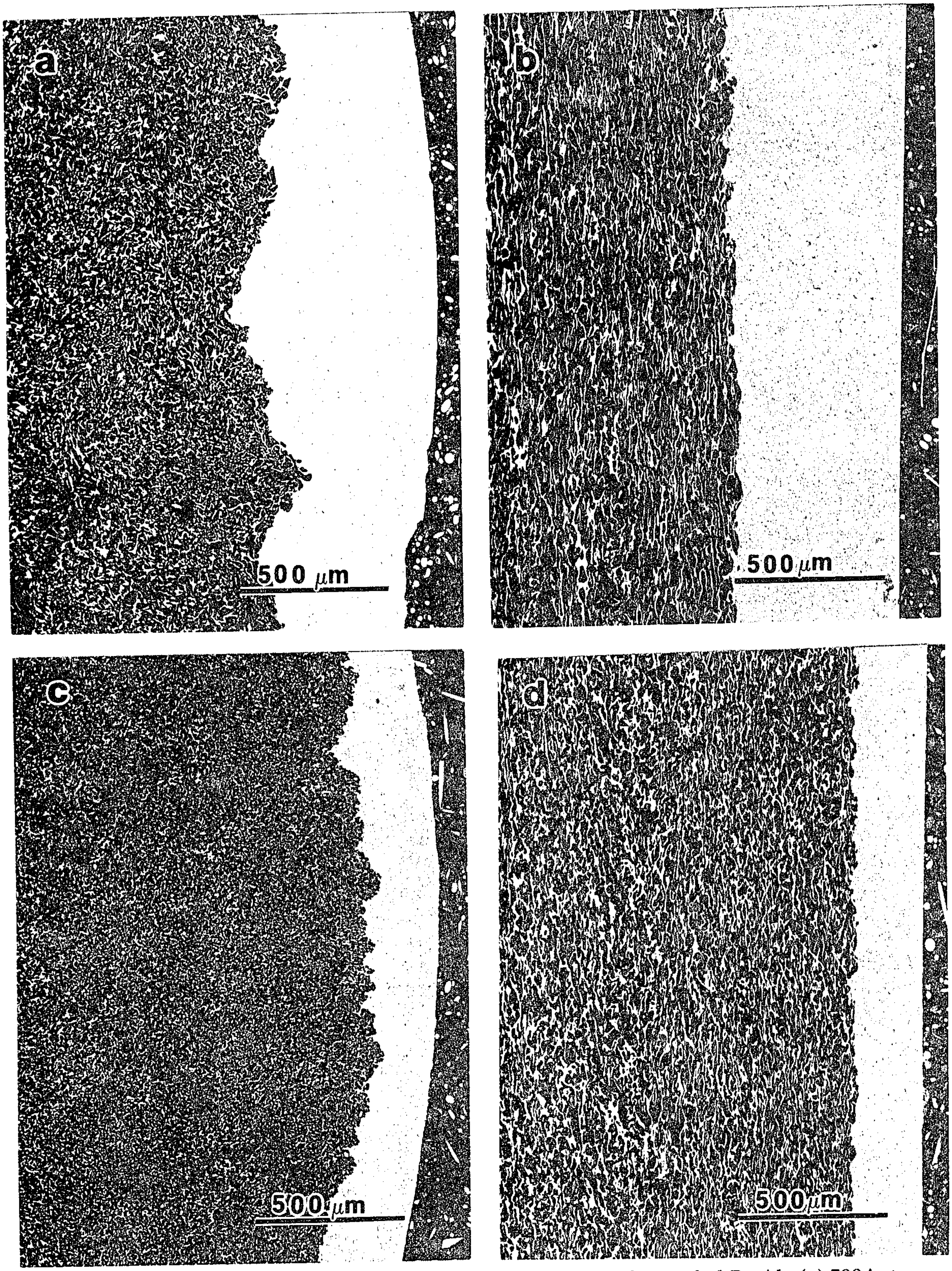

Figure 2. Backscatter electron images showing Al clad surfaces of extruded Be-Al. (a) 590A, transverse section, (b) 590A, longitudinal section, (c) 590B, transverse section, (d) 590B, longitudinal section.

4.0 Work Planned Through Next Reporting Period

All work for Task 1 and Task 2 will be completed in the next reporting period culminating in the issuance of the final report for this program. Delays in the completion of the final two extrusions planned under Task 1 have resulted from unforeseen difficulties encountered by the plasma spray vendor in obtaining 6061 aluminum powder to be used for the plasma spray coatings. These problems have been resolved, and these extrusions should be completed the first week of January. Work on Task 2 will proceed concurrently.

5.0 Conclusions

Results of Task 1 have demonstrated the capability of extruding cast beryllium-aluminum ingots with either an aluminum or copper clad surface. Preparation for Task 2 extrusions, which will lead to the development of extrusion technology for extrusion of beryllium-aluminum through a die of complex shape, is in progress.